



# Preservative effect of *Tetraclinis articulata* and *Cedrus atlantica* wood extractives against fungal decay

Efecto preservador de los extractivos de maderas de *Tetraclinis articulata* y *Cedrus atlantica* contra el biodeterioro por hongos

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## ABSTRACT

Testing environmentally-friendly plant essential oils for their ability to protect non-durable wood against wood decay fungi is a research topic of current interest. In this study, wood preservative potential of extracts from the wood of the durable species, *Tetraclinis articulata* and *Cedrus atlantica* were assessed on non-durable maritime pine sapwood, *Pinus pinaster* var *atlantica*, after exposure to three wood decay fungi, according to the EN 113 Standard. Significant differences were observed between treatment effects of these extracts, between fungal decay levels and between oils concentrations. Overall, mean mass losses of treated wood specimens were above 8%. *T. articulata* root burl extract gave the best protection level for this type of wood against *Gleophyllum trabeum* and *Rhodonia placenta* but only at test concentrations above 0.1% v/v. However, efficacy levels of both extracts' treatments, applied at the tested concentrations, were judged insufficient on the basis of the NF EN 113 standard used.

KEYWORDS: durable woods extracts, eco-friendly preservation, NF EN 113, transferable durability, wood decay fungi.

## RESUMEN

Ensayar la extracción de aceites esenciales de con técnicas amigables con el ambiente para su uso como protector de maderas susceptibles a hongos es un tema de investigación vigente. En este estudio, se evaluó el efecto protector de los aceites extraídos de la madera naturalmente resistente de *Tetraclinis articulata* y *Cedrus atlantica* de la madera del pino marítimo, *Pinus pinaster* var *atlantica*; la albura de la especie fue expuesta al ataque de tres hongos, de acuerdo con la norma europea NF EN 113. Se observaron diferencias significativas entre los efectos del tratamiento, entre los niveles de descomposición por los hongos utilizados y también entre las concentraciones de los extractivos. Los niveles medios de pérdida de masa de las muestras de madera tratadas fueron en general superiores a 8%. El aceite extraído de la raíz de *T. articulata* proporcionó el mejor nivel de protección para este tipo de madera contra *Gleophyllum trabeum* y *Rhodonia placenta*, pero solo con concentraciones superiores a 0.1% v / v. Sin embargo, los niveles de eficacia de ambos tratamientos, aplicados en las concentraciones probadas, se consideraron insuficientes sobre la base del estándar utilizado.

PALABRAS CLAVE: extractivos de maderas durables, preservación ecológica, NF EN 113, durabilidad transferible, hongos de la madera.

## INTRODUCTION

Atlas cedar, *Cedrus atlantica* Manetti, is an endemic softwood species of Pinaceae of North Africa. Its population covers the North African mountains and specifically those of Morocco and Algeria (M'hirit & Blerot, 1999). The Atlas cedar forest provides annually, in Morocco, between 80 000 m<sup>3</sup> and 100 000 m<sup>3</sup> of wood logs intended for sawing and veneer. Thuya, *Tetraclinis articulata* (Vahl) Masters, another softwood species of Cupressaceae, is an endemic tree of the western Mediterranean areas and it is a specific tree of the semi-arid temperate and hot bioclimate. In North Africa, thuya is located in a large altitudinal fringe and occupies an area of approximately 566 000 ha in Morocco (M'hirit & Blerot, 1999).

Both resinous tree species present great ecological and socio-economic interest as they are mainly recognized for their durable timbers (M'hirit & Blerot, 1999) but are unfortunately threatened (International Union for Conservation of Nature [IUCN], 2018). They have durable wood with excellent physical properties (El Azzouzi & Keller, 1998; Dakak, 2002; Fidah et al., 2015; 2016a). Extracts from wood of these trees showed antioxidant, anti-inflammatory, antiseptic, antifungal, and antiparasitic properties that indicates a promising application in wood protection against decay fungi (Derwich, Benziane, & Boukir, 2010; Kirker, Clausen, Blodgett, & Lebow, 2013; Bourkhiss, Chaouch, Ouhsine, Bourkhiss, & Rassam, 2015). Primary processing these timbers can generate second products estimated for *C. atlantica* at 30%. This waste material can be used to produce important and appreciable amounts of extractive compounds (Aberchane, Fechtal, & Chaouch, 2004; Bourkhiss et al., 2015).

Wood is a highly valued material for various uses. To limit the risk of biological deterioration, the protection of a wood for a specific use class, requires good knowledge of its natural durability (Dirol & Dégilde, 2001). Wood extractives contain many bioactive compounds involved in its inherent strength, especially against wood decaying fungi and xylophagous insects (Haluk & Roussel, 2000; Chittenden & Singh, 2011, Kirker et al., 2013; González-

Laredo et al., 2015; Mankowski, Boyd, Hassan, & Kirker, 2016; Hassan, Mankowski, Kirker, & Ahmed, 2017; Hassan, Mankowski, Kirker, Clausen, & Sohail, 2018). Among various compounds of plant extracts tested on some wood decay fungi, thymol and carvacrol were the most active compounds (Karmen, Bojana, Vrtacnik, & Pohleven, 2003). Action of phenolic compounds on fungi is primarily based on the inhibition of fungal enzymes containing SH group in their active site (Celimene, Micales, Ferge & Young, 1999; Cowman, 1999).

Clean technologies using physical and chemical processes for wood preservation have recently emerged. Research on wood preservation has recently focused on more eco-friendly treatments based on natural compounds including heartwood extracts (Dulbecco & Luro, 2001; Goodell, Qian, & Jellison, 2008; Kirker et al., 2013; Mankowski et al., 2016; Hassan et al., 2017; 2018).

## OBJECTIVES

This work aimed to assess the protective effect of extracts from heartwood of *Cedrus atlantica* and *Tetraclinis articulata*, on maritime pine sapwood, *Pinus pinaster* var *atlantica*, exposed to wood decay fungi in laboratory tests according to the European standard NF EN 113.

## MATERIALS AND METHODS

### Wood material for obtaining extracts

*Tetraclinis articulata* root burl samples were collected from sweepings of craft processing workshops in Khemisset region (Central plate of Morocco), while the sample of *C. atlantica* sawdust was collected during winter 2016 from a wood sawmill in the Azrou region (Middle Atlas Mountains of Morocco) from heaps of waste on site. A total of five hermetic dark bags of 100 liters of sawdust were transported in covered vehicle to laboratory.

### Extraction method and chemical analysis

Both sawdust samples were crushed with blade crusher and sieved to obtain a particle size of 1 mm and samples of 250 g were then subjected separately to hydrodistillation, in a



Clevenger apparatus (Aberchane et al., 2004; Sadgrove & Jones, 2015), for four hours to obtain extracts in form of oils separated from hydrosol (aqueous part) according their densities and stored in dark vials at 4 °C.

In previous works, chemical analysis was performed (Fidah et al., 2016a; 2017) by gas chromatography (GC), type Hewlett-Packard (HP 6890), equipped with a capillary column HP-5 provided by H<sub>2</sub>/air gas mixture and split-splitless injector heated at 250 °C with a split mode of injection. The column temperature was programmed from 50 °C (isothermal 5 min) to 250 °C (isothermal 10 min) in a step of 4 °C/min. The vector gas used was N<sub>2</sub> at a rate of 2 ml/min. The injected volume was one µl. The GC/MS analysis was performed on a HP 6890 equipped with an automatic injector (HP 7683) and coupled with a mass spectrometer (HP 5973) equipped with a capillary column HP-5MS. Fragmentation was made by electronic impact under the 70 eV field. The carrier gas was helium with a flow rate set at 2 ml/min and the column temperature was programmed from 50 °C to 250 °C with step of 4 °C/min. The identification of constituents was achieved based on retention indices relative to (C8-C22) n-alkanes mixture with those of the literature and gas chromatography/mass spectrometry (GC/MS) by matching their recorded mass spectral library of the GC/MS data system (Adams, 2007) and other published mass spectra.

### Preparation of test specimens

Maritime pine sapwood (*Pinus pinaster* var *atlantica* Ait) is considered as non-durable against fungal decay (Fidah et al., 2016b). Boards, of 1 m length having 25 mm × 15 mm of section, of maritime pine sapwood were taken from logs of 36 years old trees originated from the Maamora plantation (North-West of Morocco, 34°07'N – 6°36'W). Wood specimen's density was 0.567 and it measures 2.5 cm radially, 1.5 cm tangentially and 5 cm longitudinally according NF EN 113. Specimens were randomly cut from nine central plates taken from three trees. All specimens were free of cracks, discoloration, biological attack, insect holes and other defects. Specimens were conditioned to an

equilibrium moisture content of 12% in a climatic chamber set at 22 °C and 65% relative humidity. Periodically, weight measures of wood moisture content were carried out until the equilibrium was obtained.

### Fungal strains

Wood decay basidiomycetes fungi, *Gloeophyllum trabeum* (BAM Ebw.109 strain), *Rhodonia placenta* (FPRL 280 strain), and *Coniophora puteana* (BAMEbw. 15 strain), were used to test the antifungal properties of extracts. These were chosen due to significant decay potential on wood and wood-based products (Morell, 2011; Kirker et al., 2013). Fungal strains were obtained from the mycological collection of the Laboratory of Botany, Mycology and Environment, Faculty of Sciences in Rabat, Morocco.

### Antifungal activity test and evaluation

We followed the methodology described in Fidah et al. (2016a; 2017) to determine extracts' test concentrations for our tests. Extracts dilutions were prepared in xylene as a solvent to achieve five concentrations ranging from 0.033% to 0.4% v/v in addition to control (xylene only). We used 4 specimens per concentration for each fungus tested. Anhydrous specimens were submerged in solutions under pressure of a 0.7 kPa ± 0.1 kPa for 2 hours in desiccators, and then the specimens were wiped with filter paper and weighed to determine the quantity of the retained treatment solution in the pine specimens. For each concentration, specimens were placed in the same bottle and conditioned after treatment in a climatic chamber at 22 °C and 70% moisture content for 4 weeks.

For each extract, a total of 186 specimens were treated. The distribution of wood specimens, by type of test and fungus, according EN 113 standard (ECS, 1996), is given in table 1. Before treatment, conditioned samples were oven-dried for 18 hours at 103 °C to determine their anhydrous mass ( $m_0$ ) and kept dried until impregnation.

Meanwhile fungal strains were cultured in Petri dishes on malt-agar medium (20 g/l malt extract and 15 g/l agar in tap water) and then transferred after 10 days to 15 days

onto the same medium in 500 ml square bottles. Each bottle, containing 30 ml of media, was inoculated with fungi then plugged with cotton. Small round 2 mm thick stainless-steel pellets were used as holders and placed between the mycelium surface and bottom surface of the wood specimens. Conditioned specimens  $e_1$  and  $e_{2,1}$  were exposed together to mycelia as two specimens per bottle and incubated in a dark climatic chamber ( $RH = 70\% \pm 5\%$ ,  $T = 22^\circ C \pm 2^\circ C$ ) for 16 weeks. At the end of the incubation period, specimens were removed from the culture bottles, carefully brushed and immediately weighed ( $m_2$ ) to determine their final moisture content before oven drying at  $103^\circ C$  for 24 hours for a final anhydrous mass ( $m_3$ ). Mass losses for all inoculated wood specimens and average mass loss for each fungal exposure was calculated. Mass loss in percentage (ML) of each specimen ( $e_1$ ,  $e_{2,1}$ ,  $e_{2,2}$ , and  $e_3$ ) and the mean mass loss for each treatment extract-fungal strain was calculated via:

$$ML = \frac{(m_0 - m_3)}{m_0} * 100$$

where  $m_0$  and  $m_3$  are initial and final anhydrous masses of wood specimens, respectively.

TABLE 1. Distribution of maritime pine wood specimens, by type of test and fungus, according to EN 113 standard.

Fungi	Type of specimens*			
	$e_1$	$e_{2,1}$	$e_{2,2}$	$e_3$
<i>Gleophyllum trabecatum</i>	24	24	6	
<i>Rhodonia placenta</i>	24	24	6	24
<i>Coniophora puteana</i>	24	24	6	

\* $e_1$ : Treated and inoculated specimens,  $e_2$ : Untreated and inoculated specimens incubated with  $e_1$ ,  $e_{2,1}$ : Untreated and inoculated specimens for virulence check (Natural durability),

$e_3$ : Treated and not inoculated specimens used for mass loss correction.

For each treatment extract concentration-fungi strain, the corrected mass loss for virulence specimens ( $e_1$ ) was obtained by removing mass loss obtained from the  $e_3$  specimens.

The validity of the results required that wood specimens not satisfying the following conditions, had to be rejected:

- ✓ The moisture content of specimens after test must be between 25% and 80% and
- ✓ Mean mass loss of  $e_{2,2}$  specimens, used for virulence check, must be greater than or equal to that of the control specimens for each fungi strain.

### Statistical analysis

ANOVA was performed to analyze the data of mass losses from each treatment followed by Duncan's multiple range tests at  $p < 0.05$  level using Statistica 13.2 (Statsoft) software.

### RESULTS

Chemical analysis revealed that extract of *T. articulata* wood is rich in thymol, 3-tera-butyl-4-methoxyphenol, cedrol, and  $\alpha$ -cedrene, while that of *C. atlantica* is dominated by atlantones, , 5-isocedranol, 9-iso-thujopsanone, cedranone and cedroxide (Table 2).

ANOVA of the durability test data revealed high significant differences of the effects of the two studied oils between treatments, between decay levels of fungi tested and between extracts concentrations. No interaction was found between extract type and fungal strain, between extract type and concentrations, or between fungal strain and extract concentrations (Table 3).

Results from the Duncan's multiple range tests on extract efficacy, *T. articulata* root burl extract gave good results (Mass loss of about 13%). Regarding decay levels, the fungal strains were separated into three homogeneous groups, with superiority for *C. puteana* decay level (Mass loss of about 17%). Four homogeneous groups were distinguished between treatment concentrations of extracts from *T. articula* and *C. atlantica* with a measurable effect of 0.4% and 0.03% v/v concentration, with mass losses of 12% and 19% respectively (Table 4).



TABLE 2. Main components (in %) identified, by GC-MS, extracts of *Tetradiumis articulata* and *Cedrus atlantica* wood (Fidah et al., 2016a; 2017).

Component <sup>a</sup>	RT <sup>b</sup>	Kovàts Index	Thuya Root Burl	Atlas Cedar Wood
camphor	15.49	1143	-	1.28
hexyl Isobutyrate	15.57	1150	-	1.38
thymol	21.23	1290	39.80	-
α-cedrene	24.98	1409	7.77	-
β-cedrene	25.23	1434	1.80	-
α-himachalene	26.66	1447	1.07	-
thujupsadiene	26.74	1462	1.10	-
3-tera-butyl-4-methoxyphenol	27.49	1491	24.70	-
α-deshydro-ar-himachlene	28.25	1511	-	1.13
γ-deshydro-ar-himachlene	28.73	1529	-	1.57
Tumerol	30.27	1578	-	3.45
cedrol	31.12	1596	6.35	1.90
cedranone	31.61	1620	-	4.13
9-iso-thujopsanone	31.87	1637	-	4.45
α-acorenol	31.92	1633	1.10	-
β-acorenol	32.04	1637	1.30	-
himachalol	32.45	1647	0.30	2.45
5-isocedranol	32.95	1669	-	11.70
deodarone	33.23	1694	-	1.07
E γ-atlantone	34.06	1701	-	19.73
cedroxyde	34.19	1704	-	2.38
Z α-atlantone	34.41	1713	-	4.02
β-santalol	35.08	1741	-	2.00
E-Z-farnesol	35.31	1742	-	1.10
benzyl benzoate	35.78	1762	-	1.16
E α-atlantone	36.21	1773	-	16.86
14 hydroxy-murolene	36.34	1775	-	1.00
14 hydroxy δ- cadinene	36.38	1799	0.24	1.94
Z-β-santalol acetate	37.24	1823	-	1.15
β-himachalene	37.64	1499	1.25	0.79
Z-ternine	37.79	1838	-	1.25
totarol	49.34	2314	1.50	-

<sup>a</sup> Mode of identification: Retention time (RT in mn) measured to n-alcanes (C8 to C22) using capillary column (HP-5) and mass spectra were obtained using capillary column (HP-5M).

<sup>b</sup> Ratio of each peak area to the total area of the GC chromatogram (in %).

TABLE 3. Result of ANOVA for mass losses of maritime pine wood treated with different concentrations of *Tetraclinis articulata* and *Cedrus atlantica* wood extracts.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
EO type	0.097	1	0.097	30.106	0.000000
Fungal strain	0.135	2	0.068	21.058	0.000000
Conc. v/v	0.121	5	0.024	7.511	0.000004
EO type x Fungal strain	0.016	2	0.008	2.447	0.091309
EO type x Conc. v/v	0.005	5	0.001	0.327	0.895885
Fungal strain x Conc. v/v	0.007	10	0.001	0.203	0.995607
EO type x Fungus strain x Conc. v/v	0.015	10	0.001	0.466	0.908802
Error	0.347	108	0.003		

HS, high significance; NS, non-significance

TABLE 4. Results of Duncan test on mass losses of maritime pine wood treated with different concentrations of *Tetraclinis articulata* and *Cedrus atlantica* wood extracts.

	Number of observations	Mass loss %*	Homogeneous groups
<b>Extracts</b>			
<i>T. articulata</i>	72	13±5	a
<i>C. atlantica</i>	72	16±4	b
<b>Fungal strains</b>			
<i>Gleophyllum trabeum</i>	48	12±5	a
<i>Rhodonia placenta</i>	48	14±4	b
<i>Coniophora puteana</i>	48	17±3	c
<b>Concentrations % v/v</b>			
0.4	24	12±4	a
0.2	24	13±4	ab
0.1	24	14±5	ab
0.05	24	14±4	ab
0.033	24	15±5	b
0	24	19±3	c

\* Corrected mean mass loss followed by standard deviation.

Statistical analysis revealed differences between extracts concentrations effects of *T. articulata* root burl oil on *G. trabeum* and *R. placenta* strains. For *C. atlantica* wood oil, no differences between concentrations were found for any fungi (Table 5). Mean mass losses of treated wood specimens were above 8%.

The guidance of NF EN 113 standard requires levels of mass loss less than 3% for the treatment to be effective.

According to this required condition, both extracts, applied at the tested concentrations, did not provide sufficient protection to maritime pine sapwood for external uses (CTBA, 2011). Further tests must be carried out adjusting extract concentration and treatment pressure, in order to determine the potential effectiveness of the wood extractives from these tree species.



TABLE 5. Mass losses (%) of maritime pine sapwood treated by *T. articulata* root burl extract and *C. atlantica* wood extract and exposed to three wood decay fungi

Decay Fungus	Conc. % v/v	<i>T. articulata</i> root burl extract		Preservative Uptake kg/m <sup>3</sup> ***	<i>C. atlantica</i> wood extract		Preservative Uptake kg/m <sup>3</sup>
		MLe <sub>1</sub> %*	MLe <sub>2,1</sub> %**		MLe <sub>1</sub> %	MLe <sub>2,1</sub> %	
<i>Gleophyllum trabeum</i>	0.4	8.24 <sup>a</sup>	23.53	2.2	13.94 <sup>a</sup>	16.39	2.5
	0.2	9.49 <sup>a</sup>	23.43	1.1	14.66 <sup>a</sup>	17.39	1.2
	0.1	9.49 <sup>a</sup>	24.60	0.4	16.96 <sup>a</sup>	18.34	0.5
	0.05	10.06 <sup>a</sup>	22.39	0.3	17.63 <sup>a</sup>	19.42	0.4
	0.033	11.76 <sup>b</sup>	24.05	0.1	17.64 <sup>a</sup>	22.05	0.2
	0	15.25 <sup>b</sup>	23.75	0.00	20.19 <sup>a</sup>	24.60	0.00
<i>Rhodonia placenta</i>	0.4	10.16 <sup>a</sup>	22.43	2.9	15.71 <sup>a</sup>	24.21	3.1
	0.2	10.58 <sup>a</sup>	22.99	1.4	15.62 <sup>a</sup>	25.28	1.6
	0.1	10.48 <sup>b</sup>	23.65	0.6	16.34 <sup>a</sup>	26.97	1.1
	0.05	10.97 <sup>b</sup>	22.10	0.3	17.85 <sup>a</sup>	27.98	0.5
	0.033	11.00 <sup>b</sup>	26.72	0.2	19.35 <sup>a</sup>	27.63	0.3
	0	16.97 <sup>b</sup>	22.03	0.00	23.10 <sup>a</sup>	32.51	0.00
<i>Coriophora puteana</i>	0.4	14.86 <sup>a</sup>	24.87	3.2	12.27 <sup>a</sup>	15.46	2.2
	0.2	15.79 <sup>a</sup>	25.02	1.3	13.20 <sup>a</sup>	15.74	1.6
	0.1	15.82 <sup>a</sup>	26.21	0.6	13.85 <sup>a</sup>	16.09	1.0
	0.05	15.77 <sup>a</sup>	24.28	0.3	14.21 <sup>a</sup>	16.62	0.6
	0.033	17.16 <sup>a</sup>	22.77	0.2	14.61 <sup>a</sup>	17.78	0.3
	0	18.70 <sup>a</sup>	24.42	0.00	16.08 <sup>a</sup>	19.37	0.00

\*MLe<sub>1</sub>%: Corrected mass loss of treated and inoculated specimens, \*\*MLe<sub>2,1</sub>% mass loss of untreated and inoculated specimens incubated with ei. \*\*\*Calculated immediately after pressure treatment, leaching phenomenon during conditioning period not evaluated.

For each decay fungus, MLe<sub>1</sub>% values followed by the different letters shared significant differences at 95% (Duncan test); values are means of four wood specimens.

## DISCUSSION

The biocide effect of plant derived compounds have been previously reported (Boulogne, Loranger-Merciris, Ozier-Lafontaine, Desfontaines, & Petit, 2012; Singh & Singh, 2012; Kirker et al., 2013). Testing chemical friendly plant extracts for the protection of non-durable woods against wood decay fungi is a popular topic (Singh & Singh, 2012; Kirker et al., 2013; Pánek, Reinprecht, & Hull, 2014; Hassan et al., 2017; Bahmani & Schmidt, 2018). Our efforts to increase the durability of maritime pine sapwood by

durable woods extracts, represents a challenging example for eco-friendly wood preservation using plant extracts.

Extracts from sawdust of *T. articulata* and *C. atlantica* woods, ranged from very durable to durable against wood decay fungi (Fidah et al., 2015; 2016a), possess strong antifungal activity in bioassays (Fidah et al., 2016a; 2017). The transfer of high durability to less-durable woods by extractive treatment remains experimentally feasible. In our study, an increase of the durability of maritime pine sapwood treated with durable wood extracts was observed as noticeable decay levels of treated wood specimens were

lower than that of untreated. This was especially notable for *T. articulata* root burl extract but only for concentrations above 0.1% v/v.

In bioassay, *T. articulata* root burl extract showed very strong inhibitory effect against the three fungi strains tested. A total minimal inhibitory concentration of 0.025% v/v was observed. Concentrations for *C. atlantica* wood extracts needed to be higher at 0.1% v/v (Fidah *et al.*, 2016a; 2017). Higher antifungal activity observed in *T. articulata* root burl extracts is probably related to their alcohols fraction that is rich in phenols (thymol and 3-terabutyl-4-methoxyphenol) (Fidah *et al.*, 2017). Thymol and carvacrol contained in extracts of *Thymus bleicherianus* P. and *Origanum compactum* B., has been reported to possess strong antifungal activity against the same decay fungi (El Ajjouri *et al.*, 2008; Ghanmi, Satrani, Thevenon, Elyounssi, & Ajjouri, 2015). Extracts from *Lavandula angustifolia* Miller, *Cymbopogon winterianus* Jowitt, and *Thymus vulgaris* L. were also found to be effective against wood decay fungi (Bahmani & Schmidt, 2018). The antifungal activity of *C. atlantica* wood extract was previously reported and is probably due to the activity of atlantones present (Fidah *et al.*, 2016a). Chittenden & Singh (2011) reported that eugenol and cinnamaldehyde are potentially benign wood preservatives for treatment of timber not exposed to wet conditions. However, correlation of antifungal activity to a single constituent or to groups of compounds remains difficult (Hassan *et al.*, 2017; 2018).

*Cedrus atlantica* trunk wood and *Tetraclinis articulata* root burl wood contains approximately 21 l and 24 l of essential oil per cubic meter, respectively (Aberchane *et al.*, 2004; Fidah *et al.*, 2017). This most likely ensured enough protection of these woods against decay fungi. Thus, amounts of extracts applied to maritime pine sapwood (0.4 % v/v concentration) represents only a 1/5<sup>th</sup> of that found in *Cedrus atlantica* and *Tetraclinis articulata* woods and yet these amounts have improved the durability of maritime pine sapwood. Despite the leaching that occurred during the conditioning period (4 weeks) estimated for *Cedrus atlantica* and *Tetraclinis articulata* oils of about 40% to 60%

respectively (Table 5), the amounts of applied extractives remained effective against decay fungi.

Our impregnation technique needs to be optimized for this kind of treatment to be effective at commercial scale. We especially need to examine impregnation pressure and length of conditioning period before exposure of treated specimens to fungi. The treatments became less effective for ensuring the necessary wood protection during the sixteen weeks fungal exposure period (Kubicek, 2013; Bari *et al.*, 2018). Extract concentrations of about 0.5% to 1% would most likely give better protection for the period and fungi test.

Despite the success and approval of some natural extract based biopesticides (Ramzi, Ismaili, Aberchane, & Zaanoun, 2017; Hassan *et al.*, 2018), criticisms for these kinds of treatments have also been previously reported (Meikle, Sammataro, Neumann, & Pflugfelder, 2012; Pavela & Benelli, 2016). Thus, many readjustments have been recommended before considering them in Integrated Pest Management programs.

## CONCLUSIONS

The protective effect of extracts from two durable woods to improve the durability of non-durable woods was hopeful. We showed significant effect of *T. articulata* root burl extract for treatment of maritime pine sapwood against decay fungi. These findings emphasize the challenge for eco-friendly wood preservatives from natural compounds face. The development of an experimental protocol that ensures the persistence of active molecules in treated wood would be desirable and further research is warranted.

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